NUCLEAR SCIENCE AND TECHNIQUES **25**, S010603 (2014)

Local government radiation surveillance system for nuclear power plant at post-Fukushima era in China

HUANG Yan-Jun (黄彦君),[1,*] CHEN Chao-Feng (陈超峰),[1] SHA Xiang-Dong (沙向东),[1] SUN Xue-Feng (孙雪峰),[1] QIN Hong-Juan (钦红娟),[1] ZUO Wei-Wei (左伟伟),[1] ZHU Xin (朱鑫),[1] and SHANG-GUAN Zhi-Hong (上官志洪)[1]

[1]*Suzhou Nuclear Power Research Institute, CGNPG, Suzhou 215004, China*

(Received June 30, 2013; accepted in revised form September 15, 2014; published online November 20, 2014)

After the Fukushima nuclear accident in 2011, improvement actions of the environmental radiation surveillance were carried out by Chinese government to deal with the possible nuclear accident in response to the rapid development of nuclear power in China. The local government radiation surveillance system, including the on-line radiation monitoring network and automatic sampling system, the off-site monitoring center laboratory, the radioactive effluent on-line monitoring system and the sampling inspection laboratory were regulated to establish for all operation and constructing nuclear power plant. This paper describes the general design of the system by taking Ningde nuclear power plant (NPP) for example. The main designs, including radiation monitoring and sampling equipment, data collection and the communication technology, and the surveillance management, are generally based on the experiences or lessons from Fukushima accident. The system is expected to act as a pivotal role to evaluate the environmental radioactivity from the operation of NPP, and to provide effective decision support in the event of possible nuclear accident.

Keywords: Radiation surveillance system, Post-Fukushima, On-line radiation monitoring network, Effluent monitoring inspection

DOI: 10.13538/j.1001-8042/nst.25.S010603

I. INTRODUCTION

After the Fukushima nuclear accident, the experience and lesson of nuclear safety were investigated extensively by the government, nuclear industry and researchers [1–3]. The successful experience and failure lesson for environmental radiation monitoring during the accident for the operator and Japanese government were summarized. For example, the deficiency of the communication and the lack of effective monitoring facilities led to absence of supporting data in response of the nuclear accident. It was shown that an effective organization and reliable technical design of the radiation monitoring system would play a vital role in response to the nuclear emergency action [2]. The accident had waken the requirements of improving the environmental radiation system for government, and an effective surveillance of environmental radiation around nuclear facility becomes public concerns for the issues of nuclear safety. For example, in the United States, twenty percent of the US EPA's (Environmental Protection Agency) stationary radiation monitors of the nationwide RadNet system were out of service at the time of the Fukushima accident, and it was revealed that the network was severely flawed and suffers from maintenance and reliability issues, which brought the US EPA under great public crisis. After the accident, the system was extensively evaluated and improved. For example, a high speed satellite system would be procured by US EPA as a primary means of communication for fixed monitors of RadNet [4].

Over the next years, the national safety inspection of NPP was activated also in China. The reliability assessment and inspection of the environmental radiation monitoring at nuclear emergency sate for both licensees and government was launched. In May 5th, 2012, the report on the comprehension safety of the national civilian nuclear infrastructure was issued, and the recent 5-year plan for nuclear safety and radioactive pollution prevention and vision for 2020 was approved by the State Council of China [5]. The capacity improvements of emergency response and safety regulatory, the environmental safety, radioactive pollution prevention and treatment were included in the goals. In February 2012, the construction specification of off-site environmental radiation surveillance system of NPP for local government was released by Ministry of Environment Protection and National Nuclear Safety Administration (NNSA) [6]. According to the document, for all the NPP in operation and under construction, the system should be established or complemented. Up until July 2013, the systems of several NPPs were established or under construction through bid from private or public institutions, such as Ningde NPP.

The first unit of Ningde NPP was put into commercial operation in April 2013, and the local government radiation surveillance system has been accomplished according to the regulatory requirement. The design of the system drew on experiences or lessons learnt from the Fukushima nuclear accident on security safety and the data availability. The system of the radiation monitoring equipment, data collection, communication technology and the surveillance management is in state of the art. This paper will describe the design of the system according to the typical system by the case of Ningde NPP in China.

* Corresponding author, Huangyanjun@cgnpc.com.cn

II. GENERAL DESCRIPTIONS

A. Surveillance role of local government

In China, the surveillance of environmental radiation of NPP is undertaken by the local monitoring and management office, a public institution attached to local environmental protection authority. The offices have been established so far in most provinces. The capability of radiation monitoring of the office in the province with NPP is generally required to be greater. For Ningde NPP, the surveillance office is Fujian Radiation Environmental Supervision Station. The supervision scope of activities from the environmental radiation generally covered the following areas:

- Radiation and radioactivity in environment within the scope of regulation;
- Sources of radiation, including the radio-waste;
- Assessment of the environmental radiation;
- Education and training;
- Publicity.

B. General description of Ningde NPP

Ningde NPP is located in Fuding, Ningde of Fujian Province, 32 km south of Fuding, face the East China Sea on the east, and Taiwan is situated on the southeast across Taiwan Strait. Fig. 1 shows the site location of the NPP. The first stage of the NPP is to build four pressurized water reactors of CPR 1000 (Chinese Pressure Reactor 1000), and the first reactor was put into commercial operation on Apr. 18, 2013.

Fig. 1. (Color online) Location of Ningde NPP and on-line monitoring stations of the surveillance system (Z1∼Z9).

C. Analytical requirements

The surveillance of environmental radiation of operation NPP for local government is specified in the environmental protection standard of HJ/T 61-2001 [7]. The monitoring item and sampling frequency of environmental sample and effluent are generally listed in this standard according to the transport mode of radioactive release with gaseous and liquid effluent for both terrestrial and aquatic regimes. For Ningde NPP, the monitoring plan for environmental radiation is designed prior to the operation of the NPP. Table 1 shows the environmental radiation surveillance plan for Ningde NPP. The monitoring of gamma dose rate, along with the meteorological parameters, is designed with advanced probes and the redundant communication networks, and the data would be transferred on-line to the off-site center laboratory. The analytical items of air, aerosol, fallout, and rainwater rate are generally related to the frontier station. Others items would be carried out through off-line sampling and analyzing at the off-site center laboratory. All the analytical methods would be adopted through the national standard or standards released by agencies of environmental protection and nuclear industry.

The surveillance of the radioactive effluent release would be performed through on-line monitoring the radioactivity in the stack, outlet of waste gas treatment system and the liquid tanks of the nuclear power plant, and on-line sampling and off-line analyzing at the inspection laboratory. The on-line monitoring items for gaseous effluent include radioactive aerosol, iodine, noble gas, while for liquid effluent only gross gamma. The data would be collected on-line and transferred to the local office of government and NNSA. Off-line analysis of tritium, gross gamma and gamma radionuclides is performed for the liquid effluent from nuclear island and conventional island of the NPP, and the tritium, ^{14}C and gamma radionuclides for aerosol (with filters), inert gas (with sampling bottles) and iodine cartridge would be performed for gaseous effluent from waste gas treatment system. The intervals for off-line analysis depend on the effluent release and the self-schedule of the NPP.

III. DESIGN OF THE SYSTEM

A. General description

The system can be sectioned into five elements: the on-line radiation monitoring system, the automatic sampling system, the off-site center laboratory, the effluent on-line monitoring system and the effluent sampling inspection laboratory. The on-line radiation monitoring system and the automatic sampling system are designed as off-site stations for receiving control signals from and sending monitoring data to off-site center laboratory through communication network, and the off-site center laboratory is acted as the data center of the network and also for analytical laboratory for environmental sample. The effluent on-line monitoring system is designed through receiving the on-line data from the effluent monitoring from the supervised NPP, and sending to the local office

Table 1. Environmental radiation monitoring plan of the Ningde NPP

Type of sample	No. of sampling sites	Sampling or monitoring frequency	Type of analyses
Air	4	Monthly	^{131}I, ^{3}H, ^{14}C
Aerosol	4	Monthly	γ nuclides, gross α, gross β, ^{90}Sr
Fallout	4	Quarterly	γ nuclides, gross α, gross β, ^{90}Sr
Rain water	4	Monthly	^{3}H, γ nuclides, gross α, gross β
Gamma dose rate	10	On-line	Gamma dose rate
	39	Quarterly	Gamma dose rate(instantaneous measurement)
	26	Quarterly	TLD
Drinking water	3	Quarterly	^{3}H, γ nuclides, gross α, gross β
Ground water	3	Quarterly	^{3}H, γ nuclides, gross α, gross β
Sediment of surface water	4	Annually	γ nuclides,^{90}Sr
Soil	9	Annually	γ nuclides,^{90}Sr
Terrestrial biota*	3	Annually	γ nuclides
Seawater	8	Semiannually	^{3}H, γ nuclides
Bottom sediment of Seawater	4	Annually	γ nuclides,^{90}Sr
Shoreline sediment of seawater	5	Annually	γ nuclides,^{90}Sr
Marine biota*	3	Annually	γ nuclides

Note: The terrestrial and marine biota includes at least 7 types of organism respectively. For biota used as indicator, generally, pine needle, tea leaf, seaweed and oyster, the organically bounded tritium and ^{90}Sr should be analyzed annually.

of local government and NNSA. The effluent sampling inspection laboratory is established independent of that for the NPP. Both analyses are similar, but the inspection laboratory is used as supervision on behalf of the government. In summary, the system is constituted based on the regulation for the release of the radioactivity materials and the environment quality of radiation, which would allow the government to obtain and provide reliable data for public.

Figure 2 shows the configuration of the surveillance system. As indicated two monitoring types of environmental radiation and radioactivity effluent from nuclear power plant are included, and three and two elements were designed for each type respectively.

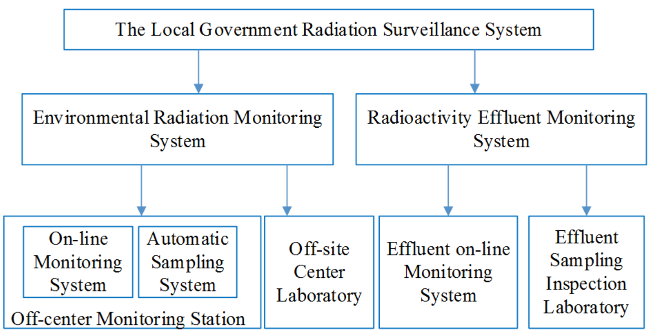

Fig. 2. (Color online) Configuration of the surveillance system.

B. Elements description of the system

1. *On-line radiation monitoring system*

(1) Monitoring sites

According to the specification of the on-line radiation monitoring network, the monitoring station is generally required to be set on equal coverage per 22.5°sector with a distance of 10 km of plume emergency planning zone (PEPZ), i.e., in each sector at least one station would be laid. For coastal NPP, the monitoring point towards the sea could be set in the light of the actual requirements. The density of the monitoring points should be increased in the directions of downside of dominant wind according on-site atmospheric conversation and with densely populated area. Besides, a control point should be set on the outside of PEPZ. Meanwhile, the condition related electricity, the communication and the geological environment should be important consideration. For Ningde NPP, ten stations were identified for the on-line radiation monitoring, and approved by the local government and NSSA. As shown in Fig. 1, Z1 to Z9 were set in the scope of PEPZ, and one control point was set on the Fuding, Fujian Province.

(2) Radiation monitoring probes

The monitoring probes were selected with both high pressure ionization chamber (HPIC) and NaI-detector. The common Geiger-Muller Counter with two or three identical counters is unselected in the system for its low accuracy. Generally, the gamma dose rate is adapted from HPIC at normal operation of the NPP, and the NaI-detector is used as an identification tool with the on-line gamma spectrum of artificial radionuclides released from the NPP. The HPIC reading interval is every 1 minute and the NaI-detector every 5 min at least. The HPIC is required installed above 1 meters above ground with measurement range of ambient dose rate of 10 nGy/h to 1 Gy/h, which allows the application of the measurement in the situation of normal background and serious nuclear accident. The NaI-detector allows recording of the in-situ gamma spectrum with least channels about 1 024 for multi-channel analyzer (MCA), and the automatic calibration to the natural present ^{40}K peak (1 460 keV) is basically required to stabilize the energy calibration against gain fluctuations induced by changes in temperature. The efficiency calibration relating the nuclide-specific counts rate to different concentrations in

the units of Bq/m^3 and Bq/m^2 and the minimum detection activities (MDA) would be further established based on the current equipment design and the installation environment [8].

(3) Meteorological gauges
At each site, the gauges of rain intensity, wind direction and speed at a height of 10 m, and others related meteorological parameters are installed, which allows the operator to screen the possible influence of the gamma dose rate. In the situation of possible nuclear accident, the gauges can also be used as tools of wind field simulations for accident consequence assessment.

(4) Data process and communication
In a monitoring cabinet or house, a data acquisition unit is installed to record the data of gamma dose rate of HPIC, gamma spectrum of NaI-detector, the meteorological parameters and the status of sampling device. Then the data is transferred to a microprocessor and automatically transmitted to the remote server located on the off-site center laboratory of each NPP, and then to the local office of local government. The operator can also view the data through the on-line display unit. The data communication modes were required with redundant of both types of wire and wireless. The wire communication is used as the main channel for its high bandwidth characteristics, and the fiber optic communication is adopted in general. When the wire channel is terminated, the wireless channel is activated to guarantee the availability of the transmitted data within every 24 h per day, and the public wireless telephone network such as GPRS (General Packet Radio Service) or 3rd Generation (3G) network is used. In Ningde project the network of WCDMA (Wide Band Code Division Multiple Access) is used. The selection is flexible according to the requirements of the local government and the actual designs. Fig. 2 shows the block diagram of the system for Ningde NPP as a typical design.

(5) Infrastructure design For the system of Ningde NPP, an UPS system or system just with battery and inverter controller should be designed to supply the monitoring probes and the communication devices for more than 72 h for each station to meet the requirement of the data availability at the situation of external power loss. A hot-standby system and cluster technique of network server were designed to ensure the safety of the monitoring data.

The software of management for different on-line data was developed, and user-friend interfaces were designed. The functions of data acquisition, displaying, analyzing and reporting, the alert of abnormal increases of gamma dose rate and the possible detection of artificial radionuclides can be achieved.According to the experience of emergency monitoring of Fukushima, the safety design of whole system should be improved to guarantee the capabilities of the monitoring and the communication, including the resistant capabilities of typhoon, earthquake, storm and lightning. The infrastructures were sufficiently reliable. The three level of lightning protection system was designed to protect the power supply, monitoring probe and communication unit. The ground resistance is below 4 Ω through method of improving ground mesh or other grounding equipment.

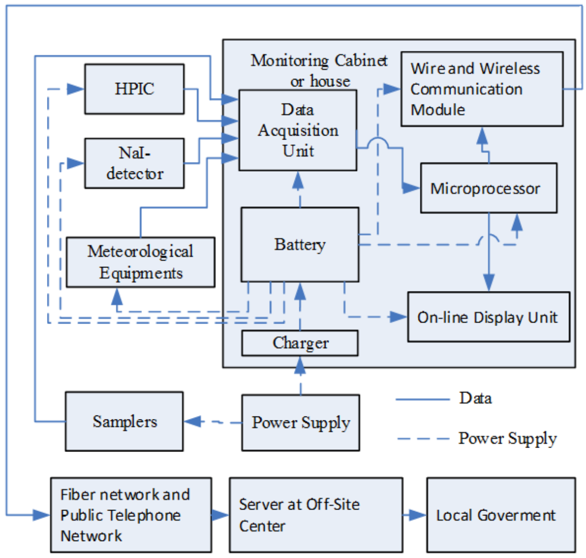

Fig. 3. (Color online) Block diagram of on-line monitoring station for the Ningde NPP project.

2. Automatic sampling system

It is regulated that the air automatic sampling system should be installed in at least 30% of on-line radiation monitoring stations. The sampling program at each station involves aerosol and gaseous iodine, airborne tritium and carbon-14, atmospheric deposition (fallout and rain water). All the samples can be obtained automatically and transferred from filed to the lab for analysis.

The general sampling flow-rate of the air particulate matters is required no less than 60 m^3/h, and at least one high volume air sampler should be installed in one of the stations with the flow rate no less than 600 m^3/h. similar to that adapted at the stations of the global Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) [9]. For the systems at Ningde NPP, the JL-900 SNOW WHITE was installed with flexible capability by changing volume flow by pump control with frequency converter. The minimum requirement of total volume of airborne particulate matter or aerosol for gamma spectrometry is about 10 000 m^3, which is can be obtained within 7 days (a week) and one day for the general sampler and high volume sampler respectively. For gaseous iodine measurement, the sampling volume is not regulated explicitly. The high volume air sampler can guarantee the rapid sampling of the air as a powerful tool in the situations of possible nuclear accident from the experience of Fukushima accident. Based on the present design, the unattended sampling and activity monitoring apparatus of air with high volume would be considered as a more effective tool in the surveillance of the environmental radiation of NPP in the future [9, 10].

The airborne tritium sampler can be used to collect the air moisture, i.e. HTO, generally with dehumidifier, while the airborne ^{14}C sampler is used to collect organic and inorganic carbon by catalysis of the organism in the air. The design of sampling of the airborne tritium and ^{14}C is the requirement of

supervisor in China as both of them are the top amount in the normal operation of the NPP.

The dry and wet deposition samples were installed in this system which allows obtaining the wet precipitation and dry fallout automatically for analyzing the radioactive matters of atmosphere. The device state and the sampling data were designed to record and be transferred to the server located at off-site center by the on-line network. A sensor was designed to trigger a lid to open or closed to obtain both dry and wet samples.

3. *Off-site center laboratory*

The off-site center laboratory is acted as a facility of environmental radiation surveillance of local government at the situation of normal operation of corresponding NPP and of the local nuclear emergency response. The server of online radiation monitoring system is situated in the center. In the normal operation of the NPP, the center is used to analyze the environmental samples surrounding the NPP within 20∼30 km independent of the operator's monitoring program to evaluate the radioactivity levels resulting from the operation of the NPP. In the center, the low background analytical instruments such as high pure germanium spectrometer, liquid scintillation spectrometer, and alpha/beta counter were installed, and the auxiliary equipment such as balance, muffle, drying oven and others for pretreatment of samples were equipped, which allowed to analyze the radioactive isotopes such as ^{90}Sr, ^{137}Cs, ^{3}H, ^{14}C and others possible artificial radioisotopes for different samples of airborne particles, fallout, rainwater, soil and sediment and biotas according to the respective monitoring programs.

In the local nuclear emergency response, the center is acted as an off-site emergency monitoring center. The mobile measurement vehicles for dealing with the nuclear emergency would be set.

As regulated for the off-site center, different types of laboratory rooms are regulated, such as sample pretreatment and preparation, radiochemical analysis and measurement. The distance of the center from NPP is generally located outside the PEPZ, which provides convenience of sampling and analyzing of the environmental sample of the NPP even in nuclear emergency response.

For the system of Ningde NPP, the off-site center lies 30 km north northwest of Fuding, a prefecture-level city. The main detectors configured in the center are shown in Table 2.

4. *Effluent on-line monitoring*

The surveillance of the radioactive effluent discharge of the NPP is also required in the system. It is regulated that the on-line monitoring data and the alert signals of liquid and gaseous effluents discharge should be transferred simultaneously to the server at off-site center by independent transmission and communication equipment. The one-line monitoring items of gaseous effluent discharge involves air particulate, iodine, radioactive inert gases, and that of liquid effluents discharge involves liquid waste from nuclear island and conventional island. All NPP should provide interfaces of data transmission of the effluent monitoring and accept supervision of the government.

5. *Effluent sampling inspection laboratory*

In order to supervise the effluent discharge of NPP, the analyzing laboratory of effluent inspection should be established. The position is generally required to build near off-site center laboratory with independent layout to avoid possible cross contamination to the environmental samples, or at the NPP site for the convenience of sampling.

The inspection items are similar to that of the NPP licensee's but with relatively lower sampling frequencies. It is used to monitor the discharge of the radioactive materials from the gaseous and liquid effluents. The primary measurement instruments for effluent inspection are similar to that listed in Table 2.

IV. SUMMARIES

(1) In the Post Fukushima Era, the requirement of environmental radiation surveillance of NPP leads to an enormous development for the local government in China. The on-line radiation monitoring network and the off-site center laboratory are regulated to construct for every operated and constructing NPP, and the supervision even extends to the radioactive gaseous and liquid effluent. The experience and lessons are drew from the emergency monitoring of Fukushima accident in Japan on security safety and the data availability.

(2) The system should be designed according to China standard and the experience from the Fukushima nuclear accidents. The safety performance and the data availability of the system are required to improve based on the infrastructure construction of disaster prevention, such as lightning protection, power supply, and the technical design of communication, the radiation probe selection for radiation monitoring network, the installation of automatic air sampling system. Typical designs of the whole system of Ningde NPP were introduced.

(3) It should be noted that with the comprehensive improvement of the system, the management requirement and the operational mechanics should be simultaneously improved to take full advantages of the design and the finance. More unified, practical and standardized monitoring systems and method should simultaneously improve with the development of the nuclear power and the regulatory requirements.

Table 2. Main equipment for environmental radiation analysis in off-site center of Ningde NPP

Instrument	Manufacturer and model	Number	Applications
Ultra low level liquid scintillation counter(LSC)	PerkinElmer Quantulus 1220	1	^{3}H, ^{14}C analysis
Low background broad Energy Ge Detector (HPGe)	Cannberra BE3830	1	γ nuclides analysis
Low background Alpha/Beta detector	Ortec Protean MPC9604	2	Measurement of total α total β, ^{90}Sr,^{137}Cs

[1] National Nuclear Safety Administration (NNSA), 2012. General technical reqirements of Post-Fukushima improvement actions for nuclear power plant.

[2] Office of Radiation and Indoor Air; U.S. Environmental Protection Agency, 2012. Expansion and Upgrade of the RadNet Air Monitoring Network, Volume 1 of 2. Conceptual Plan and Implementation Process.

[3] Huang Y J, 2011. Experiences of Response to Environmental Nuclear Emergency Monitoring After Fukushima Nuclear Accident. The 9th Conference of Radiation Protection Forum Towards 21st Century. Yangzhou, China, 251–256.

[4] Li H Y. Technol Innov Appl, 2013, **6**: 119–120. (in Chinese)

[5] State Council of China, 2012. The 12th 5-year plan for nuclear safety and radioactive pollution prevention and vision for 2020.

[6] Ministry of Environment Protection, 2012. The construction specifications of the supervision system of environmental radiation for nuclear power plant.

[7] Ministry of Environment Protection, 2001. Environment Protection Standard HJ/T 61-2001 Technical criteria for radiation environmental monitoring.

[8] Boson J, Improving accuracy of in situ gamma-ray spectrometry. Umea: Print&Media, 2008.

[9] Zhang W H, Bean M, Benotto M, *et al*. J Enciron Radioact, 2011, **102**: 1065–1069.

[10] Ungar K, Zhang W, Aarnio P, *et al*. J Radioanal Nucl Chem, 2007, **272**: 285–291.